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Novel device for evaluating sweat evaporation characteristics of woven and knitted fabrics

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This study investigates the sweat evaporation characteristics such as drying time, drying rate and drying capacity of textile fabrics objectively using novel device. The device works under the load cell principle. Using this novel device, sweat evaporation characteristics of different textile fabrics with different relative humidity have been investigated. The relationship between the new test method results and the manual test results shows good correlation.

Keywords: Bamboo, Cotton, Drying capacity, Drying rate, Knitted fabric, Load cell, Lycra, Simulated skin, Sweat evaporation, Woven fabric

1 Introduction

Thermo physiological comfort of human body could be achieved by maintaining the body temperature at 37^0C. Whatever heat produces from the human body must flow out through the clothing through the body surface. At high level of physical exertion as during sports the body must sweat; the aim being to cool the body through evaporation of the sweat. So, the clothing must ensure a high level of moisture transmission. But at very high levels of exertion, the fabric may not be able to transmit the total sweat produced to the atmosphere instantaneously. The excess sweat must be stored by the fabric for evaporation later on and the fabric should not feel wet to the wearer. Hence, a sportswear must have good air, water and heat transmission and water storage properties. It is difficult to have a textile material which has both good liquid storage and liquid transmission properties. For sportswear, single layered cotton knitted fabrics is preferred as these have greater elasticity and stretch ability compared to woven fabrics. But the problem is during high level of sweat exertion, thefabric is wet as it absorbs the sweat which is not quickly transmitted to the atmosphere. This causes a discomfort feel to the wearer.

An ideal sportswear is a multi-layered substrate which requires moisture management properties. Moisture management property is an important aspect of any fabric meant for apparels, which decides the comfort level of that fabric. It can be defined as the controlled movement of water vapour and liquid water (perspiration) from the body to the atmosphere through the fabric. Moisture management property is the prerequisite for active sportswear performance. This can be achieved in many ways, such as changing the fibre surface chemistry, usage of modified cross sectionalfibres or activated carbon fibres, yarn engineering (blending), fabric engineering and fabric chemical treatments. Moisture management tester (MMT) is developed to evaluate textile moisture management properties[1]. This method is used to quantitatively measure liquid moisture transfer in one step in a fabric in-multi directions, where liquid moisture spreads on both surfaces of the fabric and transfers from one surface to the opposite. But, it did not support to measure evaporation characteristics of textile materials. A simulated sweating skin[2] was used, over which placed test fabrics were incorporating a clothing hygrometer to continuously measure dynamic surface wetness.But, there were few attempts made on the analysis of evaporation characteristics of textile materials. Another new technique, adopted considering sweating stimulated skin for measuring the effect of fibre type on fabric surface vapour pressure and temperature, helps to assess the sensory perception of clothing comfort indirectly[3]. Dynamic moisture uptake was also studied[4-8].Modified GATS[9] was attempted to measure absorption and evaporation simultaneously.

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Assessment of sweat transmission from human body to the atmosphere is important. So far few methods have been were used for determining the water vapour permeability of textile assemblies. These are the evaporative dish method (BS 7209), the upright cup method (ASTM E 96-66), the desiccant inverted cup method (ASTM F 2298), the dynamic moisture permeable cell (ASTM F 2298), and the sweating guarded hot plate method (ISO 11092). There are some newly developed methods to test drying characteristics of textile materials[10-12].ISO 7933 and ISO 9920 refer to two methods of determination of the evaporative resistance of a clothing assembly[13].

Fangueiro *et al.*[14] studied the influence of functional fibres in the functional knitted fabrics on physiological comfort of sport garments. It was evaluated by assessing liquid transport and drying rate of the fabrics. The drying capability was assessed by drying rate tests under two different conditions, namely at 20±2°C and 65±3% relative humidity, and in an oven at 33±2°C, in order to simulate the human body temperature. Laing *et al.*[15] designed and developed the instrumental set-up to determine the drying time of a range of apparel fabrics simulating both during and after wear. The developed methods were applied to different fabrics varying in fibre content and in fabric structure.

Normally the drying time is found to be related to fabric porosity, thickness and possibly to fibre hygroscopicity. However, the drying rate is controlled by the resistance of the air layers to the passage of heat. Therefore, the thickness of the fabric and the still air near the surface are influential on the drying behavior of textile material. So far, fabric evaporation characteristics were measured by manual method, that is measurement of change in drying time and fabric weight. The present study was therefore undertaken to develop a novel test method for investigating the sweat evaporation behavior of fabrics objectively

2 Proposed Novel Device

This tester is developed in consideration with simulated skin condition and skin temperature. Further, influence of relative humidity on evaporation characteristics of textile material can also analysed. Amount of water evaporated can be measured by load cell with the help of microcontroller. The output, amount of water evaporation with respect to time can be recorded in graphical form by using lab view software.

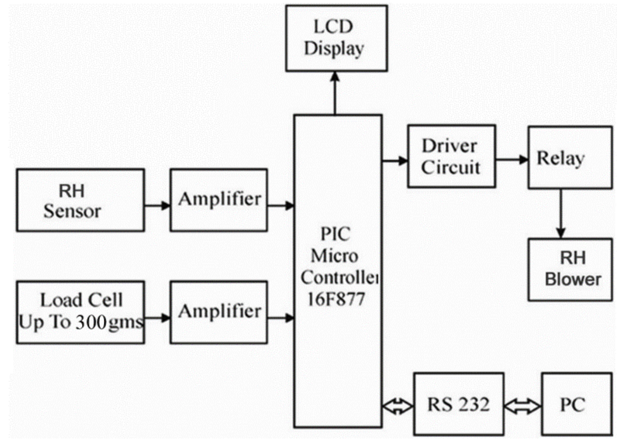

Fig. 1— Block diagram of water evaporation tester

Block diagram of the *water evaporation tester*is shown in Fig. 1. This instrument is used to measure the water evaporation characteristics of textile fabrics at different environmental conditions by varying relative humidity. The developed instrument consists of chamber, circuit with load cell for measuring the fabric weight loss with respect to time and lab view software with micro controller device for calculating the fabric drying capacity in percentage and drying rate in g/cm^2/min.

A step down transformer was used to convert 230 V to 5 V. Power supply board consisting of four diode bridge rectifiers, was used to convert AC to DC, as well as 1000 µf and 10 µf capacitors were used for filtering purposes. The power supply board supplies 5 V DC to an AT89C51 microcontroller.

The circuit with load cell is used to measure the weight loss of wet fabric with respect totime and the measured information is sent to microcontroller unit for system analysis. A load cell is nothing but force transducer which is used to convert a force into an electrical signal in terms of voltage. This conversion is indirect and happens in two stages. Through a mechanical arrangement, the force to be sensed is deforming a strain gauge. The strain gauge converts the deformation (strain) to electrical signals. The load cell consists of four strain gauges in a Wheatstone bridge configuration. The electrical signal output is normally in the order of a few mill volts and requires amplification by an instrumentation amplifier before it can be used. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

2.1 Fabric Weight Measurement

Procedure to calculate fabric weight (fabric size 8 × 8 inch) through embedded coding is discussed hereunder.

The fabric to be tested is placed on load cell. Load cell deforms based on the weight of fabric. This deformation is measured as an electrical signal. The obtained electrical signal is amplified and sent to microcontrollers through analog input terminal. Procedural steps are shown below:

- The selected load cell to measure fabric evaporation = 0 – 300g
- Rated capacity of load cell = 0.3 kg (300 g)
- Rated output of load cell = (output/input) 1 millivolt/1 volt
- Rated load capacity of load cell in voltage = 10 millivolt

To know output voltage from load cell for 1 g weight: 1g: 300 g = X mv : 10 millivolt

Hence, X= 10/300 or X = 0.033 millivolt

When 8 × 8 inch fabric is placed on load cell, the measured output load cell voltage is 0.472 millivolt. Hence,

$$\text{Weight of fabric} = \frac{\text{Measured output voltage of load cell}}{\text{Voltage per gram of load cell}}$$

$$= \frac{0.472 \text{ millivolt}}{0.033 \text{ millivolt}}$$

Weight of 8 × 8 inch fabric = 14.33 g

The output of load cell is connected to microcontroller and the above conversion values are implemented in microcontroller program to get fabric evaporation value.

In order to maintain and simulate the skin temperature, it is proposed to design a closed chamber consisting of two rooms by separating it using perforated sheet. The closed chamber size is 16 × 12 × 12 inches. The first chamber consists of sample holder for placing the test sample and this holder is connected to the load cell unit and also RH sensor is placedon the chamber. It is used to measure and controlling the chamber RH based on the set value and sent the information to micro controller. A separate RH blower is fixedon the second chamber for circulating the conditioned RH air in tofirstchamber through perforated sheet (Fig. 2).

The function of RH blower is to blow conditioned air into fabric sample which is placed in the first chamber. To test textile fabric evaporation behavior, we prepared 8 inch × 8 inch size square fabric sample, soaked it in the water and removed the excess water by hanging in a pin rod.The sample was used for a test, considering the removal of excess water from wet sample at a rate of one drop per minute. The specimen was placed on the load cell holder. Set the required RH in the instrument and switch on the RH air blower. Now the conditioned air is sucked and sent to the first chamber through the perforated sheet by the RH air blower. The RH sensor monitors the current RH and sends this information to the microcontroller. If the RH is above the set value then the blower is switched off through microcontroller. On the other hand, if the RH is less than the set value

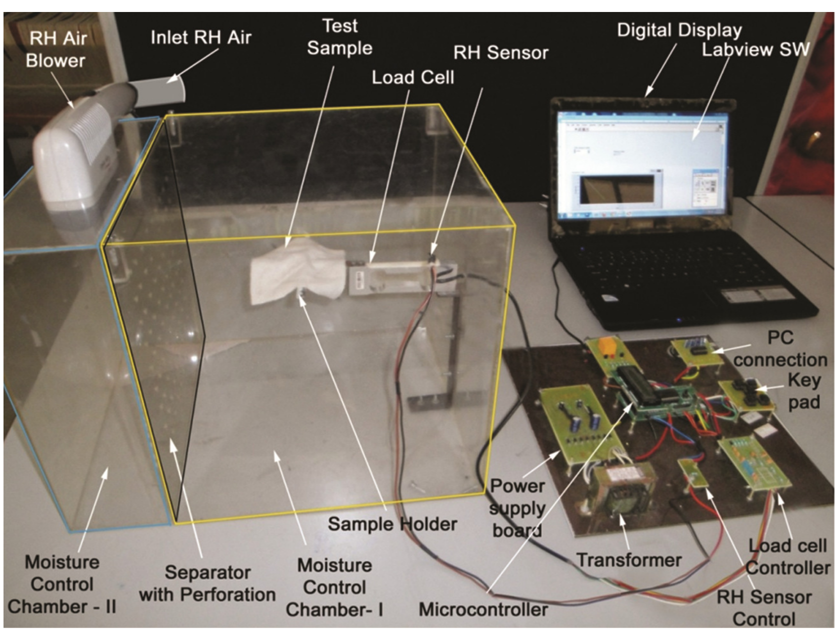

Fig. 2 — Water evaporation tester – Pictorial view

in chamber, the air blower is switched on for blowing air. Wet fabric sample weight reduces due to evaporation of water and the change in the weight is recorded on computer. The recorded values are converted into drying rate using lab view software.

3 Materials and Methods

The fabric samples were tested for their count, thickness and weight as per the international standards. Yarn count was testedwith aid ofbeesley balance using ASTM D1059-01 standard. The fabric thickness was measured with the aid of thickness gauge according to ISO 5084:1996 method. The fabric areal density (g/m^2) was measured using an electronic scale according to ISO 3801:1977 method. Fabric areal density and thickness were measured at ten different places in the fabric in each case. The fabric specifications are given in Table 1. The purpose of selected construction is to produce fabrics with different areal density. When the fabric areal density varies, the absorption and evaporation behavior of the fabrics will vary.

4 Results and Discussion

Water evaporation characteristics, such as evaporation rate, drying capacity and drying time of different textile fabrics have been assessed using new evaporation tester and the results are compared with manual method.

4.1 Drying Time, Capacity and Rate

Drying time is the time required to evaporate known quantity of water. Initially, the original fabric sample is weighed (W1), then wetted by adding 10 mL of water and weighed again (W2). Time required to evaporate the intake water (W2 – W1) on fabric is noted; ten milliliter water quantity is selected based on the water retention behavior of selected samples.

Drying capacity of the fabric is the per cent loss of fabric weight during evaporation at a particular time interval.

Time required to evaporate the intake water on fabric is calculated as drying rate.Table 2 shows that 8 inch × 8 inch fabric sample with 10 mL of water has been used to evaporate water using the new tester, and 0.41 g of water is evaporated within 5 min of time interval, as shown below:

Calculation of drying rate

Water evaporated in 5 min **:** 0.41 g

Water evaporated in 1 min **:** 0.082 g (for8 × 8 inch of fabric)

Water evaporated for 1 m ^{2}fabric **:** $\frac{0.082\ g}{8 \times 8} \times 39.3^2$

Drying rate **:** 1.98 g/m^2/min (for 10 mL water intake of fabric)

Water evaporated for 1 m ^{2}/mL/min**:** 0.198 g/m^2/mL/min

Water evaporated for 1 m ^{2}/mL/h**:** 11.88 g/m^2/mL/h

Table 1 — Fabric specifications

Sample code	Structure	Count Ne	Warplinear mass, Ne	Weft linear mass, Ne	Warp or wale per cm	Weft or course per, cm	Thickness mm	Areal densitygsm
S1	Cotton , plain - woven	30	30	30	48	26	0.34	150
S2	Cotton , plain – woven	60	60	60	60	20	0.21	70
S3	Cotton , plain – woven	60	60	60	60	24	0.21	80
S4	Cotton , plain – woven	50	50	50	60	24	0.22	100
S5	Cotton , plain – woven	50	50	50	48	30	0.23	100
S6	Bamboo/ cotton knits	40	40	-	80	140	0.56	220
S7	Cotton/lycra, knits	30	30	-	80	160	0.80	280
S8	Cotton - pique, knits	40	40	-	80	150	0.71	240
S9	Cotton/fleece, knits	40	2/ 40	-	80	120	1.35	400

Table 2 — Evaporation characteristics of sample (S1) fabrics

Time, min	Manual method				New method			
	Sample + water g	Water evaporation amount, g	Drying capacity, %	Drying rate	Sample + water g	Water evaporation amount , g	Drying capacity, %	Drying rate
0	14.33	-	-	-	14.33	-	-	-
5	13.92	0.41	5.20	1.98	13.96	0.37	4.67	1.79
10	13.59	0.74	9.79	1.79	13.59	0.74	9.79	1.79
15	13.21	1.12	15.60	1.80	13.14	1.19	16.74	1.91
30	11.9	2.43	41.40	1.95	11.90	2.43	41.40	1.95
60	9.71	4.62	125.54	1.86	9.52	4.81	137.82	1.93
90	7.52	6.81	457.05	1.83	7.34	6.99	533.59	1.87
120	6.4	7.93	2143.24	1.59	6.30	8.03	2974.07	1.61
180	6.25	8.08	3672.73	1.08	6.24	8.09	3852.38	1.08

Based on above procedure other samples like S2, S3, S4, S5, S6, S7, S8 and S9 are tested with both the methods (manual and proposed tester) and values are given in Table 3.

The relationship between two methods, such as manual and proposed method is analysedwith respect to drying capacity and drying rate of the fabrics. In the case of the drying capacity test, the correlation coefficient between manual and new test method is found0.994 and the correlation coefficient between manual and new test method for drying rate is 0.992.

4.2 Influence of Relative Humidity on Drying Behaviour

In order to study the influence of relative humidity (RH %)on drying behavior of selected fabrics, three levels of RH are chosen (49, 60and 72 %), based on the fact that one is nearstandard value and other two are higher and lower as compared to standard value. Drying time of the fabric samples is noted from 0 min to 120 min for every 5 min, with three levels of RH (Table 4). The effect of RH on drying behaviour of the fabric samples is analysed and reported in Table 5. Influence of RH on drying time irrespective of fabric samples, and the influence of RH on drying time

Table 3 — Evaporation characteristics of different fabrics

Time min	Drying rate, g/m^2/min															
	Manual								Instrumental							
	S2	S3	S4	S5	S6	S7	S8	S9	S2	S3	S4	S5	S6	S7	S8	S9
5	0.92	0.92	2.61	2.41	1.59	0.87	2.99	2.27	1.35	1.45	2.27	2.70	1.74	0.58	2.75	2.41
10	1.35	1.47	2.97	1.93	1.52	0.87	2.20	2.05	1.38	1.50	3.28	2.27	1.93	1.28	1.98	1.81
15	1.32	1.58	2.38	2.99	2.33	1.62	2.46	2.09	1.35	1.61	2.41	2.20	1.85	1.62	2.28	1.93
30	1.48	1.71	2.24	2.30	1.88	1.63	1.86	1.79	1.46	1.58	2.22	2.40	1.89	1.73	1.60	1.78
60	1.59	1.40	1.83	1.87	1.83	1.58	1.49	1.76	1.61	1.61	1.91	1.99	1.89	1.68	1.41	1.63
90	1.33	1.13	1.30	1.39	1.82	1.62	1.61	1.58	1.33	1.20	1.33	1.41	1.83	1.62	1.50	1.60
120	1.09	0.91	1.03	1.09	1.77	1.59	1.50	1.56	1.09	0.92	1.00	1.08	1.84	1.65	1.41	1.55

Table 4 — Evaporation characteristics of different fabrics by varying relative humidity

Drying time min	Relative humidity, %	Drying capacity, g/m^2/mL/min								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
Wet	RH-49	14.33	8.26	7.49	8.72	9.16	20.96	24.46	23.51	28.91
	RH-60	14.33	8.26	7.50	8.70	9.16	20.95	24.46	23.51	28.90
	RH-72	14.33	8.26	7.49	8.66	9.14	20.95	24.46	23.21	28.71
5	RH-49	13.99	7.99	7.34	8.25	8.61	20.62	24.54	22.99	28.52
	RH-60	13.96	7.98	7.20	8.23	8.60	20.59	24.34	22.94	28.40
	RH-72	13.95	7.99	7.17	8.22	8.59	20.54	24.01	22.91	28.36
10	RH-49	13.67	7.73	6.92	7.39	8.24	20.16	24.15	22.72	28.27
	RH-60	13.59	7.69	6.88	7.34	8.22	20.15	23.93	22.69	28.15
	RH-72	13.54	7.67	6.84	7.33	8.21	20.14	23.71	22.66	28.02
15	RH-49	13.25	7.52	6.61	7.20	7.81	19.76	23.94	22.13	27.81
	RH-60	13.14	7.42	6.50	7.20	7.79	19.80	23.45	22.09	27.70
	RH-72	13.10	7.37	6.51	7.21	7.75	19.71	23.38	22.06	27.69
30	RH-49	11.91	6.51	5.62	5.97	6.22	18.63	22.45	21.57	26.86
	RH-60	11.90	6.45	5.53	5.94	6.18	18.60	22.31	21.52	26.69
	RH-72	11.86	6.41	5.50	5.91	6.14	18.54	22.16	21.51	26.69
60	RH-49	9.88	4.27	3.59	3.98	4.26	16.31	20.36	20.05	24.89
	RH-60	9.52	4.26	3.50	3.94	4.20	16.25	20.28	20.01	24.84
	RH-72	9.40	4.26	3.46	3.91	4.14	16.28	20.26	19.93	24.83
90	RH-49	7.34	3.32	3.06	3.76	3.91	14.20	18.62	17.90	22.93
	RH-60	7.34	3.30	3.02	3.75	3.90	14.11	18.40	17.90	22.93
	RH-72	7.34	3.26	3.00	3.74	3.86	13.97	18.35	17.97	22.97
120	RH-49	6.33	2.91	2.96	3.73	3.81	11.81	16.31	16.76	21.37
	RH-60	6.30	2.82	2.95	3.73	3.81	11.80	16.25	16.50	21.20
	RH-72	6.28	2.79	2.95	3.73	3.82	11.78	16.21	16.08	21.00

Table 5 — Effect of RH on drying behavior of fabric samples - Significance test

Drying time	Effect on drying time[a]		Effect on drying time[b]		
min	F ratio - calculated	F ratio –tabulated	Fabric sample	F ratio - calculated	F ratio –tabulated
Wet	0.0002	3.40	S1	0.0031	3.56
5	0.0005	3.40	S2	0.0019	3.56
10	0.0005	3.40	S3	0.0050	3.56
15	0.0007	3.40	S4	0.0005	3.56
30	0.0004	3.40	S5	0.0010	3.56
60	0.0005	3.40	S6	0.0009	3.56
90	0.0002	3.40	S7	0.0202	3.56
120	0.0010	3.40	S8	0.0057	3.56
			S9	0.0056	3.56

[a]Irrespective of fabric sample.
[b]Irrespective of drying time intervals.

irrespective of drying time intervals have been studied. The results show that three different RH levels have insignificant difference in their drying behaviour of the fabrics.

The developed equipment will measure the evaporation rate dynamically without human error using newly developed embedded microcontroller programme with lab view software. Further data can be stored and retrieved for future analysis. Additional attachment such as conditioned air inlet and RH sensor will maintain exact controlled atmosphere, to study the influence of RH. The difficulty in manual measurements is to record the evaporation values at specified interval for long time, which is difficult to control the environmental temperature.

5 Conclusion

The sweat evaporation characteristics of human body using simulated by newly designed tester. The sweat evaporation on human body could be measuredin terms of drying time, drying rate and drying capacity. The relationship between the proposed method and the manual measurement shows good correlation. The influence of RH on drying behavior of the selected fabrics shows insignificant results and the device is found useful for the development of sportswear product development.

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